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SEASONAL VARIABILITY OF TSPM, PM10 AND PM2.5 IN AMBIENT AIR AT AN URBAN INDUSTRIAL AREA IN EASTERN CENTRAL PART OF INDIA

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ABSTRACT

Total Suspended Particulate Matter (TSPM), PM_{10} and $PM_{2.5}$ were simultaneously monitored during the year 2015 at Raipur, an industrial-urban location in eastern-central part of India. Sampling was carried out using high volume sampler, respirable dust sampler (PM_{10}) and fine particulate ($PM_{2.5}$) samplers. Samplers were operated for 24 hours (8-hour cycles for TSPM and PM_{10}) on several days covering the five main seasons. Daily TSPM, PM_{10} and $PM_{2.5}$ average concentrations varied between, 44.50 and 566.22 (mean: 277.85±170.81 $\mu g/m^3$); 37.30 and 344.57 (mean: 162.69±71.74 $\mu g/m^3$); 18.92 and 229.77 (mean: 108.31±40.41 $\mu g/m^3$); respectively. TSPM, PM_{10} and $PM_{2.5}$ mass concentrations showed distinct seasonal cycle; TSPM – (Winter; 419.49 $\mu g/m^3$) > (Autumn; 366.93 $\mu g/m^3$) > (Monsoon; 66.92 $\mu g/m^3$); PM_{10} – (Winter ; 237.10 $\mu g/m^3$) > (Spring; 185.82 $\mu g/m^3$) > (Autumn; 172.52 $\mu g/m^3$) > (Summer; 142.93 $\mu g/m^3$) > (Monsoon; 58.24 $\mu g/m^3$) and $PM_{2.5}$ – (Autumn; 132.15 $\mu g/m^3$) > (Winter; 119.56 $\mu g/m^3$) > (Spring; 115.98 $\mu g/m^3$) > (Summer; 89.87 $\mu g/m^3$) > (Monsoon; 64.71 $\mu g/m^3$). This seasonal variation may be due to the prevailing meteorological conditions, anthropogenic activities, biomass burning and autumn season festival events. Higher $PM_{2.5}/PM_{10}$ ratio during monsoon season, may be due to greater washout of the coarser particles compared to the finer. A clear inverse relationship between $PM_{2.5}$ and wind speed (r = -0.24) and PM_{10} and wind speed (r = -0.08) was found. Above findings will be helpful in; understanding seasonal variations in size distribution of particulates, source apportionment study, mitigation and air pollution control strategy.

Key words: Aerosol; Ambient air pollution; Particulate matter; TSPM, PM_{10} and $PM_{2.5}$.

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1. INTRODUCTION

Atmospheric aerosol affects regional and global climate directly by absorbing and scattering the incoming and outgoing solar radiation [1], indirectly by altering the cloud microphysical properties [2] and semi-directly by reduction in cloud coverage [3]. Aerosols also have adverse impact on human health [4].

Air pollution has become serious problem in South Asian cities, especially in industrially developed cities. To enhance the accuracy of the various available models for source apportionment study and preparation of guidelines, implementation of mitigation policy, detailed knowledge of aerosols size distribution and composition in ambient air is required. Though, several studies have been carried out in different parts of the world – Hong Kong[5], Karachi[6], Chengdu, China[7]; and India – Patiala[8], Udaipur [9], Pune[10], and Shillong [11]; however, few studies have been reported on simultaneous measurement of SPM, PM_{10} and $PM_{2.5}$ by gravimetric analysis method at the same location. Deshmukh [12] reported annual average of $PM_{2.5}$ (150.90±78.6) and PM_{10} (270.50±105.5) at Raipur, during July 2009 and June 2010. In another study, Sharma [13] found maximum PM_{10} (241.14±50.5) during winter time and minimum PM_{10} (140.10±43.9) during monsoon season at Delhi, during January 2010 and December 2011. In [14] PM_{10} ranged between 17.2 $\mu g/m^3$ and 681 $\mu g/m^3$ during the year 2014 at Baotou, China.

Raipur is the capital of Chhattisgarh state, and its economy is generally based on mineral deposits based industrial activities, such as coal-based thermal power plants, metal processing, and cement manufacturing industries. WHO report [15] published in the year 2014 and 2016, ranked Raipur at fourth and seventh place in the world, in the list of the most polluted cities of world associated with the ambient air $PM_{2.5}$ concentration. In the year 2012, seven million deaths in the world occurred, mainly due to the combined effects of ambient and household air pollution (WHO, 2014) [16].

Based on the impact of particulate matter on global climate and human health, regular monitoring of particulate matter in ambient air is needed. In the current study, TSPM, PM_{10} and $PM_{2.5}$ aerosol mass concentration are simultaneously monitored to assess the air quality throughout the year 2015 in Raipur, India, and the size specific PM mass variation (daily, seasonal), meteorological parameters influencing the PM mass concentrations are analyzed.

2. METHODOLOGY

2.1. Study area and prevailing Meteorology

Raipur district, the capital of Chhattisgarh state, is one of the leading industrial and commercial cities of central India. Raipur district is industrially developed, and it has further scope for new and up-scaling of existing industries as well.

Raipur has a tropical wet and dry climate; temperatures remain moderate except from April to June, during these months highest temperature can reach up to 48ºC. Winter season is generally during November to January; with minimum temperature reaching to 5ºC. Fig. 1 Shows site location map.

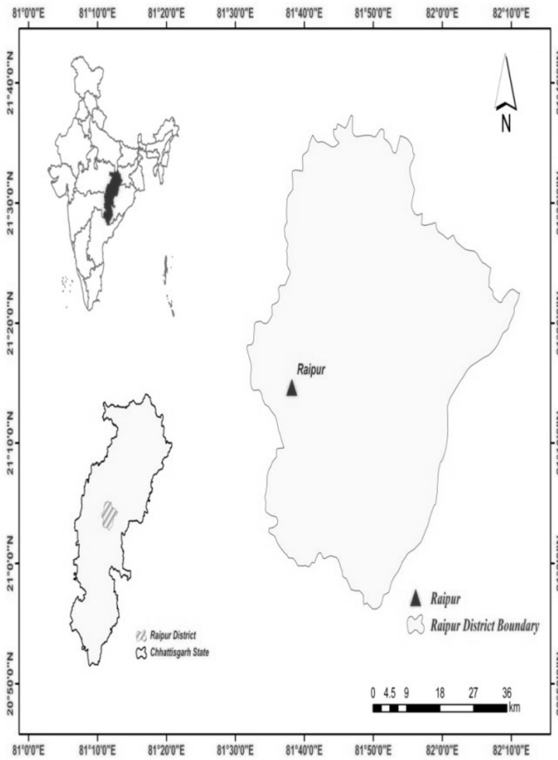

Figure 1 Shows site location map

2.2. Instrumentation and Sampling Techniques

TSPM, PM_{10} and $PM_{2.5}$ aerosol sampling was conducted simultaneously during the year 2015, on the roof top of main building (14 m above the ground level) inside the campus of National Institute of Technology Raipur, situated in Raipur. Sampling of aerosol was carried out using high volume sampler, respirable dust sampler (PM_{10}) and $PM_{2.5}$ sampler, to have the broad aerosol size distribution. Samplers were operated for 24 hours (8-hour cycles for TSPM and PM_{10}) during the year 2015. Aerosol samples were collected on Whatman glass fibre filter (8×10 inch) and Teflon (2 µm) filter of size 46.2 mm effective diameter. For conditioning, the filter papers were placed in desiccators for 24 h before and after sampling. The desiccated filter papers were weighed using balance (Precisa-92SM-202A) with 0.01 mg resolution. Aerosol concentrations were determined gravimetrically by dividing the difference in weight of the filter paper before and after the sampling with the volume of air sampled. Instrumentation and other details are given in Table no. 1.

3. RESULTS AND DISCUSSIONS

3.1. Overall Particulate Matter Concentrations

Ambient air quality standards specified by different agencies for particulate matter concentration have been summarized in Table no.2.The temporal variations of TSPM, PM_{10} and $PM_{2.5}$ concentrations and $PM_{2.5}/PM_{10}$ ratio, during 2015 are displayed in Figure no.2. Daily average of TSPM, PM_{10} and $PM_{2.5}$ concentrations ranged between, 44.50 (8^{th} September 2015) and 566.22 20^{th} November 2015), 37.30 (8^{th} September 2015) and 344.57(26^{th} December 2015), 18.92 (3^{rd} September 2015) and 229.77 (festival-Diwali; 11^{th} November 2015) µg/m^3, respectively, with mean value as 277.85±170.81, 162.69±71.74 and 108.31±40.41 µg/m^3, respectively, during the study period. PM_{10} concentration was higher during winter (237.10±62.61 µg/m^3), followed by spring (185.82±40.68 µg/m^3), autumn (172.52±66.07

µg/m^3), summer (142.93±20.79 µg/m^3), and monsoon season (58.24±16.48 µg/m^3). $PM_{2.5}$ concentration showed different seasonal pattern with highest values during autumn (132.15±46.46 µg/m^3), followed by winter (119.56±32.71 µg/m^3), spring (115.98±31.36 µg/m^3), summer (89.87±14.26 µg/m^3), and monsoon season (64.71±25.93 µg/m^3) as shown in Figure 3. Above distinct seasonal behavior may be due to the prevailing meteorological condition, anthropogenic activities, biomass burning and autumn season festival events. $PM_{2.5}/PM_{10}$ ratio during study period ranged 0.24-1.90 with average (0.74±0.29), and higher value of 1.12, during the monsoon season reveals greater washout of coarser particles as compared to the finer ones. Negative correlation of $PM_{2.5}$ and PM_{10} mass concentration with wind speed (r = -0.24 and -0.08, respectively) was observed during the study period.

Table 1 Sampling and Instrumentation details

Sampler	Model	Particulate size	Flow rate	Sampling duration	Filter paper
High Volume Sampler	APM 430/Envirotech	10µm-50 µm	0.9-1.1m$^{3/}$m^{-1}	8 hr interval	Whatman Glass Fibre Filter (8×10 inch)
Respirable Dust Sampler	APM460 DXNL/Envirotech	Aerodynamic Diameter (d)≤ 10µm	0.9-1.1m$^{3/}$m^{-1}	8 hr interval	Whatman Glass Fibre Filter (8×10 inch)
$PM_{2.5}$ sampler	APM 550/Envirotech	Aerodynamic Diameter (d)≤ 2.5µm	16.67 lpm	24 hr interval	Teflon PTFE (2 µm pore size), 46.2 mm

Table 2 Air Quality Standards

Air Quality Parameter	CPCB (NAAQS, 2009)		USEPA		WHO	
	Annual	Daily (24 Hr)	Annual	Daily (24 Hr)	Annual	Daily (24 Hr)
TSPM (µgm^{-3})	140*	200*	-	-	-	-
PM_{10} (µgm^{-3})	60	100	--	150	20	50
$PM_{2.5}$ (µgm^{-3})	40	60	--	35	10	25

*As per earlier (NAAQS-CPCB, India

3.2. $PM_{2.5}$ Daily Maximum and Minimum

Figure 2 indicates that, maximum $PM_{2.5}$ mass concentration was observed on 11th November 2015 (Diwali Festival; fire crackers burning; 229.77 µg/m^3); followed by another peak (during festival Dushehara; burning of effigy-193.89 µg/m^3) that sustained in atmosphere for next two days, this shows emission of a lot of fine particles during firecracker burning and comparative slower deposition of fine particles. Nigam [17] also reported about 8 to 9 times higher value for $PM_{2.5}$ during Diwali festival at Nagpur, during November 2014. We observed the lowest value on 3rd September, 2015; indicating effective rain washout. Yadav [9] reported (8-110 µg/m^3; $PM_{2.5}$) at Udaipur, Rajasthan, during April, 2010 to March 2011.

3.3. PM_{10} Daily Maximum and Minimum

PM_{10} mass concentration was consistently higher than $PM_{2.5}$, except during monsoon season, with lowest value on 8th September 2015 and highest value on 26th December 2015; may be due to anthropogenic activities firecrackers burning during night of Christmas festival. Sharma [18] reported average PM_{10} mass (202.30±74.30 µg/m^3; 216.20±77.40 µg/m3; 171.50±38.50

µg/m3) for Indo-Gangetic-Plain (IGP) cities; Delhi, Varanasi and Kolkata, respectively during the year 2011.

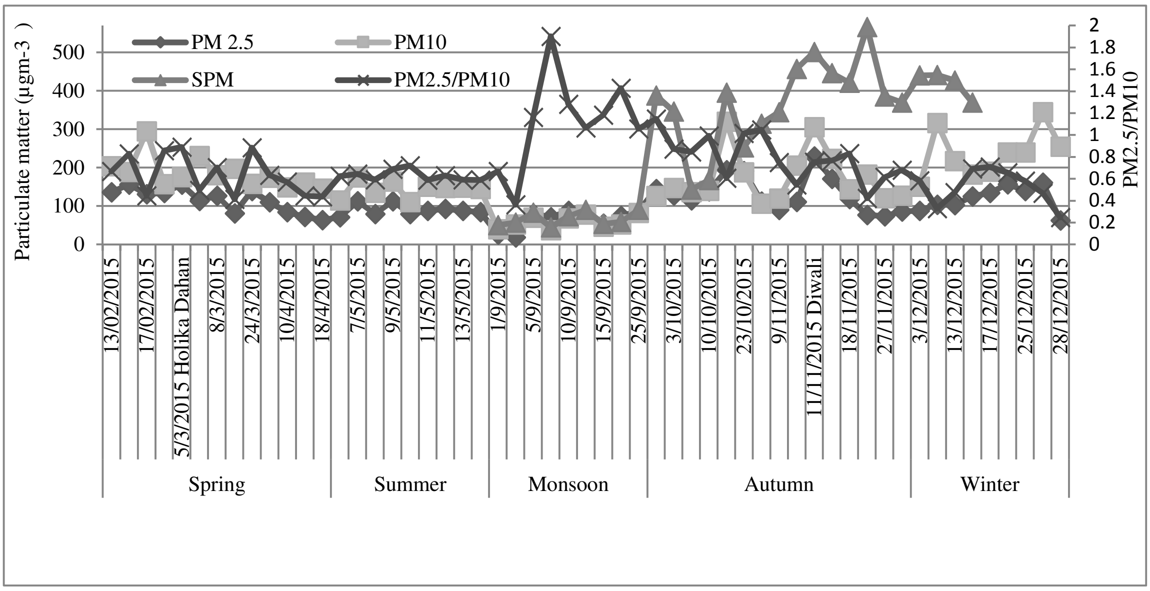

Figure 2 Variation of TSPM, PM_{10}, $PM_{2.5}$ and $PM_{2.5}/PM_{10}$

3.4. Variation in $PM_{2.5}/PM_{10}$ Ratio

We have observed $PM_{2.5}/PM_{10}$ ratio lower than one consistently throughout the study period, except during Holika-Dahan (nearly equal); (Indian festival; wood burning); monsoon and Dushehara (Indian festival; biomass burning). We also observed low ratio on 28th December, 2015 (unusual event) may be due Christmas eve. Tian [7] observed higher $PM_{2.5}/PM_{10}$ ratio in winter at Chengdu, China during the year 2006-2014. In another study [19] reported high ratio (0.70) in rural and low (0.32) at Agra roadside. Tiwari [20] found lowest ratio during monsoon month at Delhi during 1st December 2011to 30th June 2013. Low ratio revealed that coarser particles are also important in air quality studies in Raipur.

3.5. Seasonal Variation (TSPM, PM_{10} AND $PM_{2.5}$)

TSPM, PM_{10} and $PM_{2.5}$ mass concentration showed distinct seasonal cycle; SPM (Winter; 419.49 µg/m^3) > (Autumn; 366.93 µg/m^3) > (Monsoon; 66.92 µg/m^3); PM_{10} (Winter ; 237.10 µg/m^3) > (Spring; 185.82 µg/m^3) > (Autumn; 172.52 µg/m^3) > (Summer; 142.93 µg/m^3) > (Monsoon; 58.24 µg/m^3) and $PM_{2.5}$ (Autumn; 132.15 µg/m^3) > (Winter; 119.56 µg/m^3) > (Spring; 115.98 µg/m^3) > (Summer; 89.87 µg/m^3) > (Monsoon; 64.71 µg/m^3) (Figure 3). Above seasonal behavior may be due to the prevailing meteorological condition, anthropogenic activities, biomass burning and festival events, during autumn season. Lowest average PM mass concentration consistently found during monsoon season with more percentage decrease for coarser particles. In Seoul, Korea [21] found distinct seasonal pattern for PM_{10} (spring > winter > summer > fall) and $PM_{2.5}$ (winter > spring > summer > fall) during the year 2013.

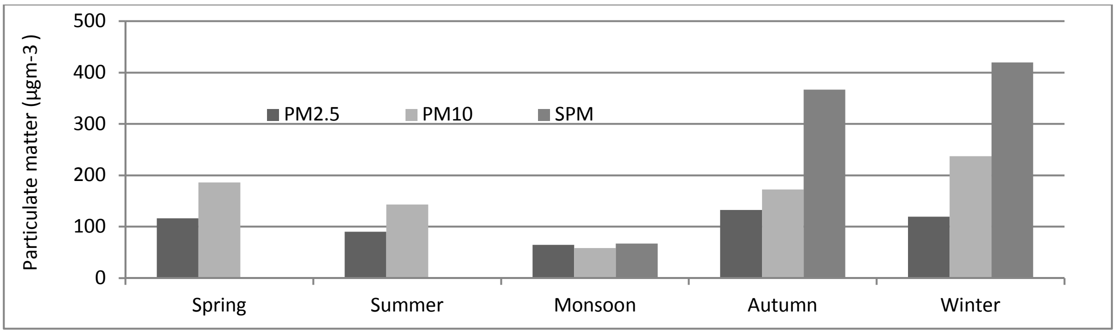

Figure 3 Seasonal variation (TSPM, PM_{10}, $PM_{2.5}$)

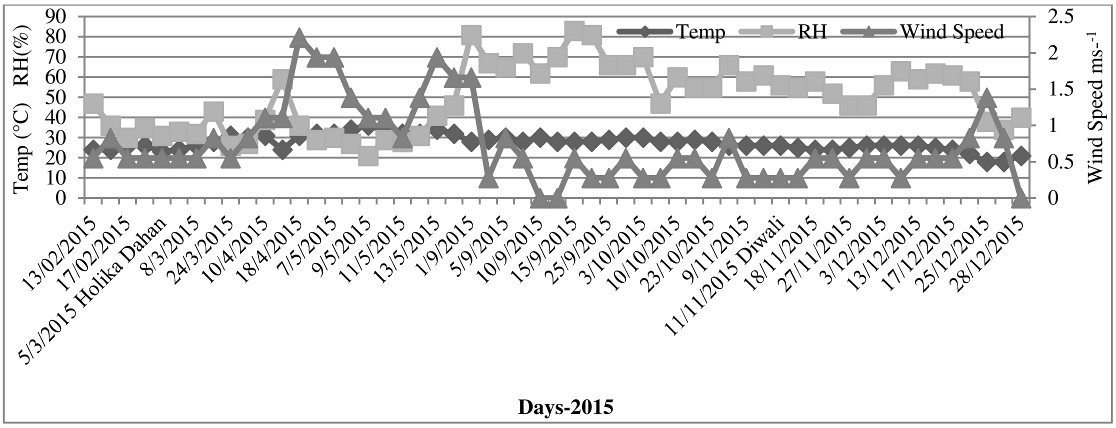

Figure 4 Variation in Meteorological Parameter

3.6. Comparison with Other Studies

Ambient air aerosol variability depends upon the location and type of sources, and prevailing meteorological parameters leading to different atmospheric conditions. During past two decades many studies have been carried out to monitor PM mass concentration over Indian region and other parts of the World. The Mean PM_{10} and $PM_{2.5}$ mass concentration during study period at Raipur is compared against values reported at same location – Raipur [22] ($PM_{2.5}$;115.0±36.0; PM_{10};246.0±68.0 µg/m^3); Raipur [23] ($PM_{2.5}$;125.10 µg/m^3); and found comparable with present study; other locations – Delhi [20] (PM_{10} :232.10±131.10; $PM_{2.5}$: 118.30±81.70 µg/m^3); Chengdu, China [7] (PM_{10} (winter:237.50.0±100.30; summer: 142.10±63.10 µg/m^3) ($PM_{2.5}$ (winter:154.0±66.20; summer:85.20±40.40 µg/m^3); Peshawar, Pakistan [24] (PM_{10} :480.0; $PM_{2.5}$: 172.0 µg/m^3) have been reported to have higher PM mass concentration as compared with the present study. Several other location in India like, Delhi [13]; (Delhi-Varanasi-Kolkata) [18] and at Baotou, China [14]; were found to have quite equal and comparable PM mass concentration at Raipur during study period. At Hong Kong, China [5], Seoul- Korea [21], Sicily- Italy [25], the PM concentrations were sufficiently lower than the values reported at Raipur. In [26-27] report published on air quality status of million plus cities by Central Pollution Control Board (CPCB) found PM_{10}: 268.0 µg/m^3 and 305.0 µg/m^3 in the year 2012 and 2013 respectively at Raipur. Ambient air particulate matter concentrations for various locations given in Table no.3

Table 3 $PM_{2.5}$ and PM_{10} aerosol mass concentrations at various cities in world.

City	Study Period	PM_{10} (μgm^{-3})	$PM_{2.5}$ (μgm^{-3})	Instrumentation Principle	Reference
Agra (India) Semi-Rural Roadside	April 2010-June 2010	234.54±128.27 278.67±106.58	89.12±37.94 90.16±7.21	Gravimetric	[19]
Chengdu (China)	2006- 2014 Winter Summer	237.50±100.30 142.10±63.10	154.00±66.20 85.20±40.40	Gravimetric	[7]
Delhi (India) (IMD -less traffic site)	December 2011-June 2013	232.10±131.10	118.30±81.7	Beta Attenuation Monitors	[20]
Delhi (India)	Jan 2010-Dec 2011 Winter Monsoon	241.40±50.50 140.10±43.90	-	Gravimetric	[13]
Raipur (India)	July 2009-June 2010	150.90±78.6	270.50±105.50	Gravimetric	[12]
Karachi (Pakistan)	March-April 2009	437.00	75.00	Gravimetric	[6]
Seoul (Korea)	2013	45.00±20.40	26.60±12.60	Beta Ray Absorption	[21]
Udaipur (India)	April 2010-March 2011	30.0-350.00 (Daily mean)	8.0-110.0 (Daily mean)	Beta Attenuation Monitors	[9]
Hong Kong (China)	Oct 2004-Sep 2005	-	55.50±25.50	Gravimetric	[5]
Shillong (India)	April 2010	73.17-265.64	81.24-261.43	Gravimetric	[11]
Patiala (India)	April 2010-June 2010	71.0-221.0	27.0-92.10	Optical (light scattering)	[8]

3.7. Meteorological Parameter Influencing Pm Mass

In this study we tried to investigate the influence of meteorological parameter over PM mass variation during the year 2015. Local meteorological parameters such as air temperature, relative humidity and wind speed and were obtained from the archives at Weather Underground (http://www.wunderground.com) (Figure 4). Statistical analysis of available data was performed for finding the correlation between PM mass concentration and meteorological parameters for the study region and duration. We found negative correlation between $PM_{2.5}$ mass concentration and wind Speed (-0.24), relative humidity (-0.17) and temperature (-0.31) and PM_{10} mass concentration and wind Speed (-0.08), relative humidity (-0.37) and temperature (-0.46). During study period temperature, ranged 18°C-36°C with minimum temperature observed during Christmas festival. Relative humidity ranged 21%-83% with minimum in summer and maximum in monsoon. Wind speed ranged (0.74 - 2.20 m/s); mostly less than 1.0m/s and found more in summer (more than, 1.0 m/s) season and during spring (2.20 m/s).

4. CONCLUSIONS

TSPM, PM_{10} and $PM_{2.5}$ were simultaneously monitored during the year 2015 at Raipur; daily average ranged between: TSPM – 44.50 and 566.22; PM_{10} – 37.30 and 344.57; and $PM_{2.5}$ – 18.92 and 229.77 µg/m^3, respectively, with mean concentration of 277.85±170.81, 162.69±71.74 and 108.31±40.41 µg/m^3 respectively, during the study period. TSPM, PM_{10} and $PM_{2.5}$ mass concentration showed different seasonal cycle; SPM (Winter; 419.49 µg/m^3) > (Autumn; 366.93 µg/m^3) > (Monsoon; 66.92 µg/m^3); PM_{10} (Winter ; 237.10 µg/m^3) > (Spring; 185.82 µg/m^3) > (Autumn; 172.52 µg/m^3) > (Summer; 142.93 µg/m^3) > (Monsoon; 58.24 µg/m^3) and $PM_{2.5}$ (Autumn; 132.15 µg/m^3) > (Winter; 119.56 µg/m^3) > (Spring; 115.98 µg/m^3) > (Summer; 89.87 µg/m^3) > (Monsoon; 64.71 µg/m^3). Lowest average PM mass concentration was consistently observed during the monsoon season with more percentage decrease for coarser particles.

We found negative correlation between $PM_{2.5}$ mass concentration and wind Speed (-0.24), relative humidity (-0.17) and temperature (-0.31); and PM_{10} mass concentration and wind Speed (-0.08), relative humidity (-0.37) and temperature (-0.46). We have observed $PM_{2.5}/PM_{10}$ ratio to be consistently lower than one throughout the study period, except during Holika-Dahan (Indian festival during spring; wood burning); monsoon season and Dushehara (Indian festival; during autumn, biomass burning).

The study shows influence of meteorological and anthropological activities, particularly festival related activities such as fire crackers bursting, effigy burning, and biomass burning on seasonal variation in concentration of particulate matter in ambient air in an urban industrial area in India.

5. ACKNOWLEDGEMENTS

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